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VHF Intrusion Detection: A Technique for Parked Aircraft

J. LEON POIRIER
NICHOLAS V. KARAS
JOHN A. ANTONUCCI
MARY SZCZYTKO, Sgt, USAF

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ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK 13441

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APPROVED:

Philipp Blacksmith

PHILIPP BLACKSMITH
Chief, Electromagnetic Systems Concepts Branch

APPROVED:

Allan C. Schell

ALLAN C. SCHELL
Acting Chief
Electromagnetic Sciences Division

FOR THE COMMANDER:

John P. Huss

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This report describes the results of tests made on a radio frequency intrusion detection system intended to protect high-value individual resources. These tests, which were designed to determine the RF field characteristics of the system, were carried out using the system in conjunction with a parked B-52 aircraft. The goals of these tests were to establish the validity of the underlying system concept and to observe its performance in a realistic environment.

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20. Abstract (Continued)

The sensor consists of a length of leaky coaxial cable that acts as a distributed transmitting antenna deployed on the ground around the parked aircraft. A centrally located monopole antenna on the ground beneath the parked aircraft receives the signal that radiates from the leaky coaxial cable. When an intruder crosses the cable sensor, the received signal is modified, producing a change in the quiescent level of the detected signal.

The results establish the viability of the monopole-leaky coaxial cable, intruder-detection concept. Three areas of performance were noted to have particularly favorable outcomes:

(a) The absence of shadowing by wheels, wing tanks, doors, or other airframe obstacles,

(b) Little effect from wind-induced airframe motion,

(c) A well defined and contained detection zone.

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VHF Intrusion Detection: A Technique for Parked Aircraft

1. INTRODUCTION

This report describes the results of tests made on a radio frequency intruder-detection system intended to protect high value individual resources. The tests were designed to determine the RF field characteristics of the system, employing it in conjunction with a parked aircraft. The goals included: establishing the validity of the underlying system concept, observing its performance in a realistic environment, and identifying areas where further refinement would be necessary. All were realized.

The inception of this new class of RF intrusion sensors[1] was motivated by the need to eliminate the severe deficiencies of systems now available or under development for this application. The principle problems are: a high false alarm rate, difficulty in controlling the extent and uniformity of the zone of protection, and critical set-up procedures. By exploiting the inherent properties of VHF signals, the new sensor would greatly reduce or eliminate deficiencies associated with current systems.

The sensor consists of a length of leaky coaxial cable that acts as a distributed transmitting antenna deployed on the ground, encircling the parked aircraft. A

(Received for publication 11 November 1977)

1. Karas, Nicholas V., Franchi, P.R., Fante, Ronald L., and Poirier, J. Leon (1977) An RF Intrusion Sensor for Isolated Resources, RADC-TR-77-118.

centrally located monopole antenna positioned on the ground beneath the parked aircraft receives a signal that radiates from the leaky coaxial cable. When an intruder crosses the cable sensor, the received signal is modified, producing a change in the quiescent level of the detected signal.

Further system details can best be explained with the help of the simplified block diagram shown in Figure 1. The low-pass a. g. c. filter sets the gain of the receiver and the level of the transmitted signal to values appropriate for existing conditions. Its frequency response allows only long-time-constant changes, such as might be produced by environmental drifts, to affect system parameters. The band-pass filter passes only those changes in the detected signal that correspond to human frame motion. The threshold detector, which requires a minimum signal change to be activated, together with the reduced cross section of small biological targets, discriminates against nuisance alarms produced by small animals. The system also includes circuits that detect high levels of external interference or other malfunctions.

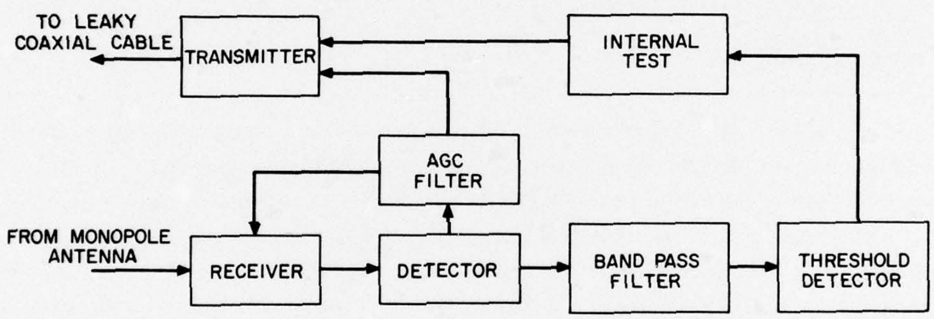

Figure 1. Simplified Block Diagram

The tests to be described are only associated with the electromagnetic fields of the system and assess three specific areas of performance. The first shows that airframe structures (wheels, doors, wing tanks, etc.) do not produce shadowing. This is to be expected because of the low frequencies (50-100 MHz) employed. The second determines the effect of wind-induced airframe motion on system output. The last was to establish the approximate limits of the zone of protection. Each factor that was determined will be fully discussed. The details of the experimental set-up will first be described to place the results in context.

2. DESCRIPTION OF EXPERIMENT

The measurements were conducted using the parked B-52 aircraft shown in Figure 2 as a typical resource. To facilitate the presentation of the measurement data, the coordinate system defined in Figure 3 will be used. A point will be identified in plane polar coordinates in terms of an azimuth angle θ and a radius ρ, or in rectangular coordinates in terms of distances (X and Y). A block diagram of the set-up is shown in Figure 4. The experiment was designed to establish the uniformity and extent of the RF field produced by the sensor cable. The support electronics discussed in connection with Figure 1 are undergoing separate evaluation at this time and will not be discussed here.

A network analyzer was used for the transmitter-receiver, providing a broad range of frequencies and detection sensitivities. The receiver output signal was recorded on the y-axis of an x-y recorder. The x-axis was calibrated in terms of azimuth angle, radial distance, tangential distance, or time. Two attenuators and a pair of coaxial switches were used to calibrate the receiver-recorder and to compensate for the attenuation in the feed cables. Most measurements were performed at 75 MHz, although some were made at other frequencies. Since the results at 75 MHz were representative of those at other frequencies in the range of 50 to 100 MHz, only the data for 75 MHz is given here. The input power to the cable was 1 MW, although the radiated power was considerably less than this because leaky coaxial cable is a very inefficient radiator. The leaky coax to monopole coupling loss ranged from 60 dB to 110 dB, with 85 dB typical.

The tests were roughly divided into three parts. The first set of tests determined the detection sensitivity of the system. This involved measuring the variation in received signal level as a person walked around the circumference of the cable. The second set determined the sensitivity of the system to wind-induced airframe motion. This was accomplished by manually moving the wing of the aircraft while monitoring the received signal. The third set determined limits on the zone of containment of the RF field. This was achieved by having vehicles move progressively closer to the cable while monitoring system operation.

Two leaky cables were evaluated during these tests. The first cable was 500 ft long (160-ft diam) and the second was 750 ft long (240-ft diam). Results of these tests will be presented separately.

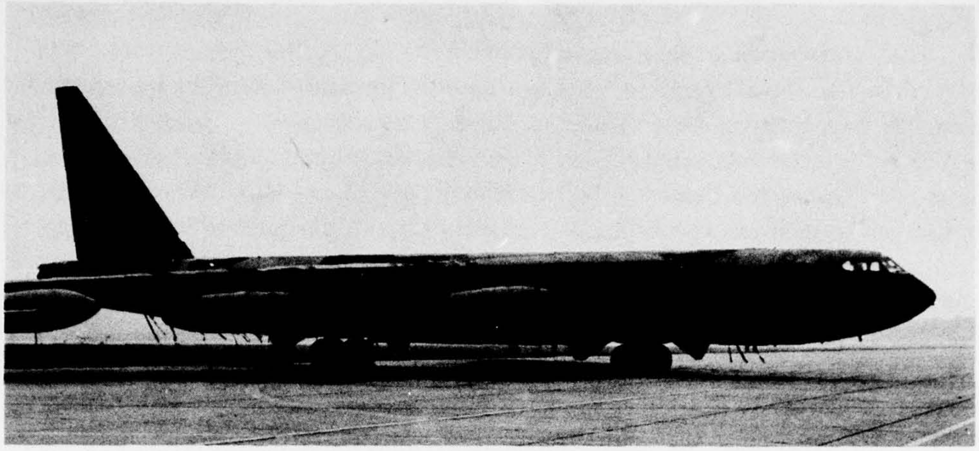

Figure 2. Photograph of Parked B-52

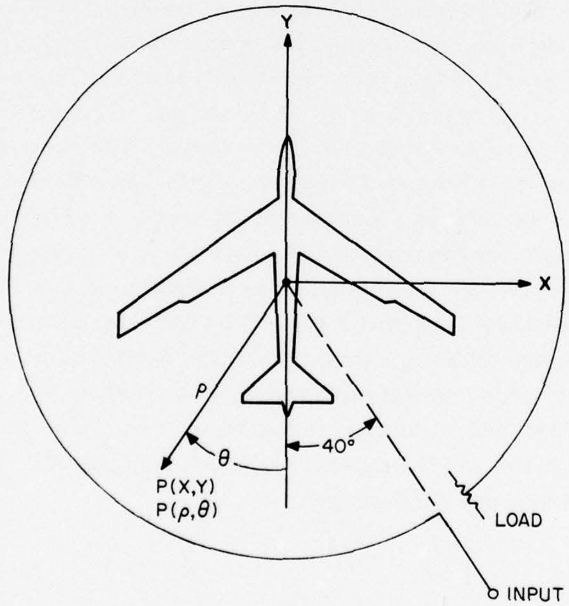

Figure 3. Coordinate System for Experiment

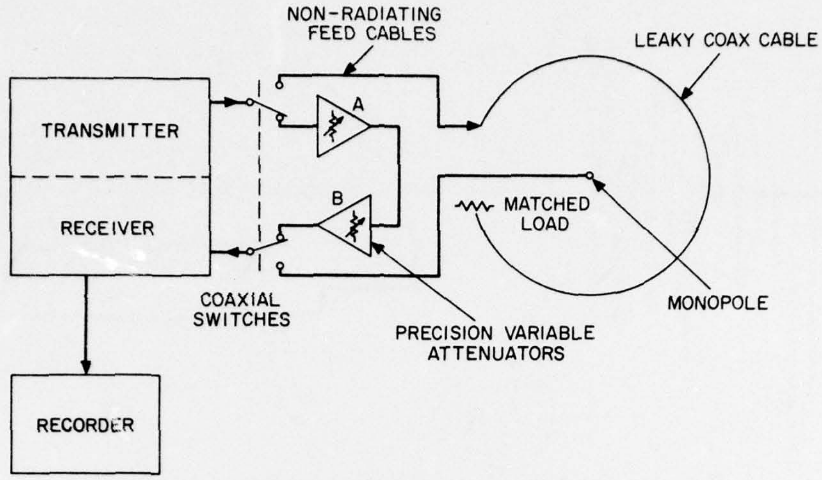

Figure 4. Block Diagram of Experiment

3. MEASUREMENTS AND RESULTS

3.1 Tests With 500-Foot Cable (160-ft diam)

3.1.1 CIRCUMFERENTIAL WALKS

For these tests, the variation in received power was recorded as a person walked around the aircraft, beginning at the tail, immediately adjacent to the cable (see Figure 5). Previous measurements had indicated that the amplitude of signal changes so produced was directly related to the detection sensitivity of the system to radial penetrations.[2] These tests were given the appellation "circumferential walks."

The initial measurements were carried out with 500 ft of leaky coaxial cable deployed in a circle approximately 160 ft in diameter around the B-52 aircraft. With this arrangement, the wings extended over the cable and crossed it in the vicinity of the wing tanks. The variations in received signal strength are produced as the phase of the perturbation changes with the walker's position. The period of these oscillations corresponds to the walker moving 1 wavelength. However, it is the amplitude, relative to the quiescent level of the envelope of this curve, that is the measure of the detection sensitivity of the system at that azimuth. The

2. Poirier, J. Leon, Karas, Nicholas V., Antonucci, John A., and Szczytko, Mary E. (1977) Intrusion Detection System for Isolated Resources, RADC-TR-77- , to be published.

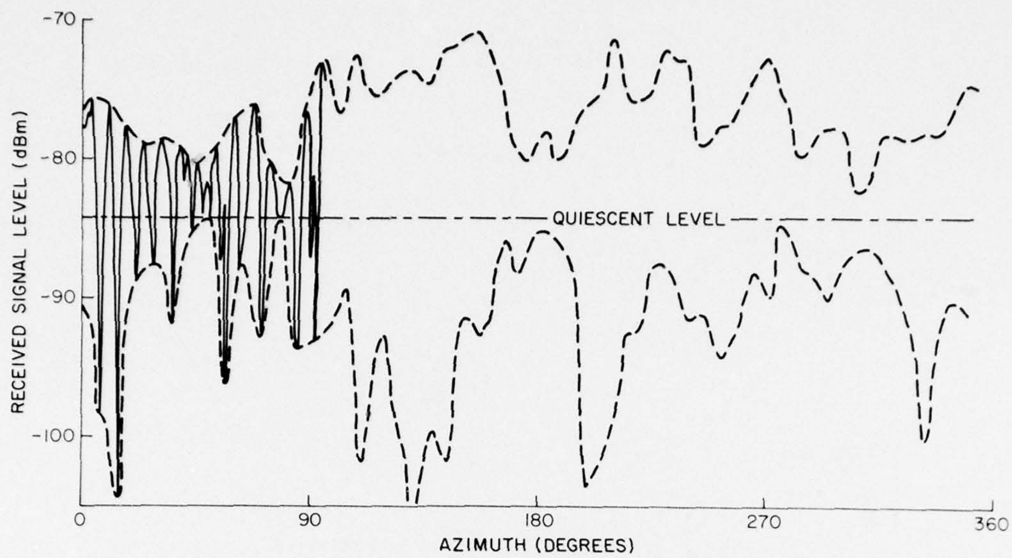

Figure 5. Variation of Received Signal for 500-Foot Cable

response, although not uniform in azimuth, shows no dead signal areas produced by shadowing effects. This data can be further simplified to show the probability of detecting an intruder. The results will be presented in this reduced format in later sections.

3.1.2 EFFECT OF WIND-INDUCED AIRFRAME MOTION

The next phase of the measurements determined the effect of wing motion on the received signal. Since the wings actually crossed the cable, it was expected that even small changes in wing position would cause a significant response in the received signal, effecting a corresponding false alarm. For these tests the wing was manually lifted in synchronism with its natural oscillating frequency. The maximum deflection achieved at the wing tip was about 1 ft.

The received signal power variation recorded during these wing oscillations is shown in Figure 6. Gradual buildup in response corresponding to the increasing amplitude of the wing displacement is evident. The maximum amplitude was achieved when the wing tip wheel touched the ground. At this point no further increase in amplitude was possible; the wing was released and its motion decayed rapidly to rest. The maximum amplitude of the change in received signal approached 6 dB.

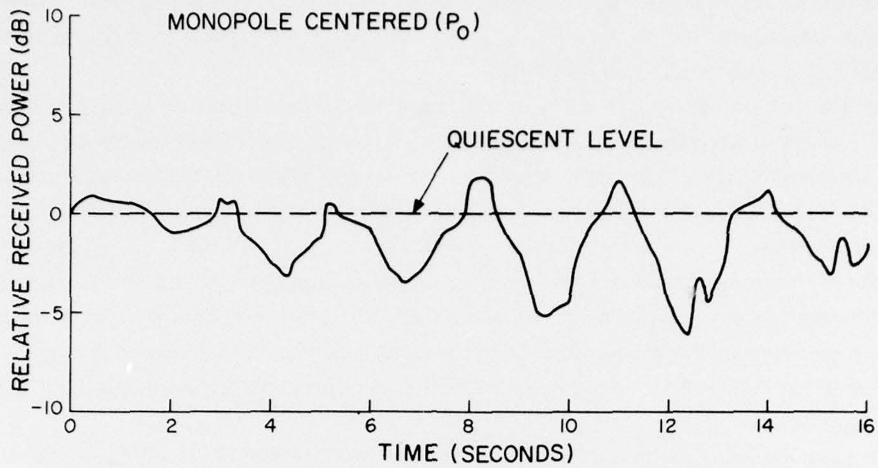

Figure 6. Variation of Received Signal Caused by Wing Motion

Inspection of Figure 6 also indicates that the natural frequency of the wing motion and, thus, that of the received signal variations was about 0.3 Hz. The signal variations produced by human frame motion range from about 0.1 to 10 Hz. Therefore, it is not possible to filter out the signal variations caused by wing motion from those caused by an intruder. In addition, the natural frequency of wing motion varies with aircraft type, fuel load, and other factors, making it difficult to predict its exact value.

From the previous discussion it is clear that the 6 dB signal change produced by wing motion exceeds that produced by an intruder penetrating at certain azimuths (see Figure 5), and that it is not possible to filter these unwanted variations. If the threshold is set to achieve a P_D of 0.95, there will be many false alarms because of wing motion. If it is set at 6 dB to prevent false alarms, there will be many sectors in which an intruder will not be detected.

Thus, the response of the system to wind-induced airframe motion was unacceptable when the cable ran beneath the wings. To eliminate this problem, the length of cable was increased to 750 ft so that the cable would extend 20 ft beyond the wing tip.

3.2 Tests With 750-Foot Cable (240-ft diam)

3.2.1 CIRCUMFERENTIAL WALKS

In this configuration, measurements were made with single and dual monopole receiving antennas located in a number of positions. Only the single monopole

located in the four positions indicated in Figure 7 will be discussed here. These positions are identified as P_0, P_1, P_2, P_3 and they correspond to y coordinates of 0, -25, 25, and 50 ft, respectively.

The envelope of the variation in the received signal with the monopole at position P_0 is shown in Figure 8. Again, although the system is not uniformly sensitive, the shadowing effect of the wheels, doors, and other obstacles is minimal.

The envelope of the received signal response (Figure 8) can be redrawn in a different format to give a clearer representation of performance. In general, an intruder will cause the received signal to increase and decrease from its quiescent value during his progression across the cable. It is the maximum of these changes, whether positive or negative, that is the measure of the sensitivity of the system. The curve in Figure 8 is redrawn in Figure 9 to depict maximum values for the polar coordinates.

A quantitative measure of the detection sensitivity was derived from the data in Figure 8 in the following manner: The bipolar envelope of the received signal was divided into a large number of uniformly distributed samples, positive excursion sample points alternating with negative. The amplitude of the response at each of these points was then tabulated. The ratio of the number of samples whose value exceeded an arbitrary threshold value (2 dB for example) to the total number of samples was computed for several threshold values.

The result of this exercise, plotted in Figure 10, is a parameter of the detection sensitivity; it depicts the probability of sensing an intruder penetrating a randomly selected location if a certain change in received signal is required to declare a detection. It should be understood that this definition of probability of detection, although consistent with that used in intrusion-detection systems, does not correspond to the one conventionally applied to radar systems.

From the curve of Figure 10, it is clear that about 95 percent of the walking penetrations will produce signal changes in excess of 1 dB. This threshold level is indicated by the dashed line in Figure 11 and represents the change that must be produced by an intruder for him to be detected 95 percent of the time (P_D = 0.95). The value of this threshold level relative to signal changes produced by false and nuisance alarm sources (to be discussed later) is a true indicator of system performance. A good system produces a large signal change for human frame intrusions, while remaining insensitive to small animals and other sources of false alarms.

Using this format, the detection performance of a system configuration can be quickly estimated and compared with other deployment arrangements.

The response curves corresponding to the three other monopole locations are shown in Figures 12, 13, and 14. Inspection of these curves clearly shows the effect of monopole location on the variation of system sensitivity with azimuth.

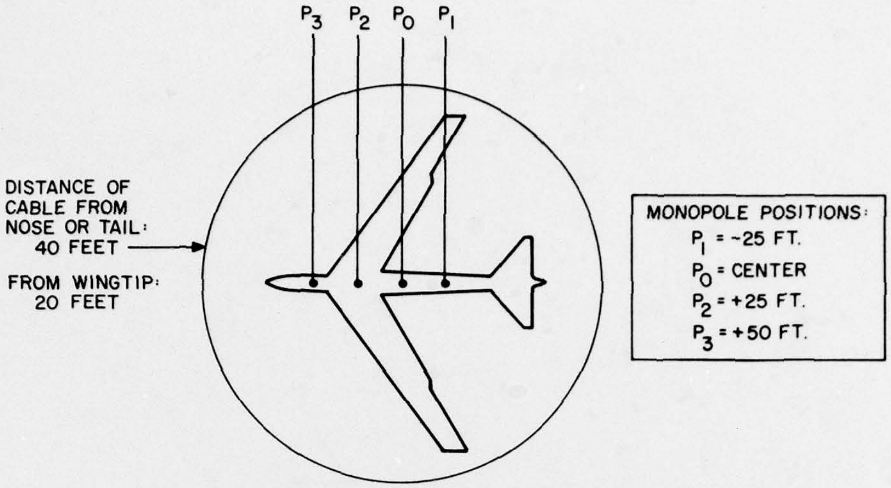

Figure 7. Experimental Set Up for 750-Foot Cable

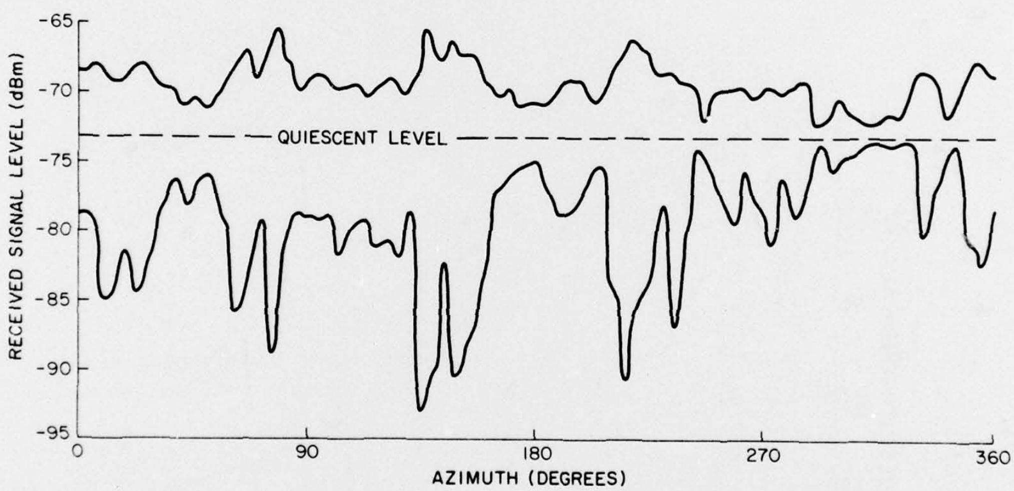

Figure 8. Bipolar Response for Central Monopole Position

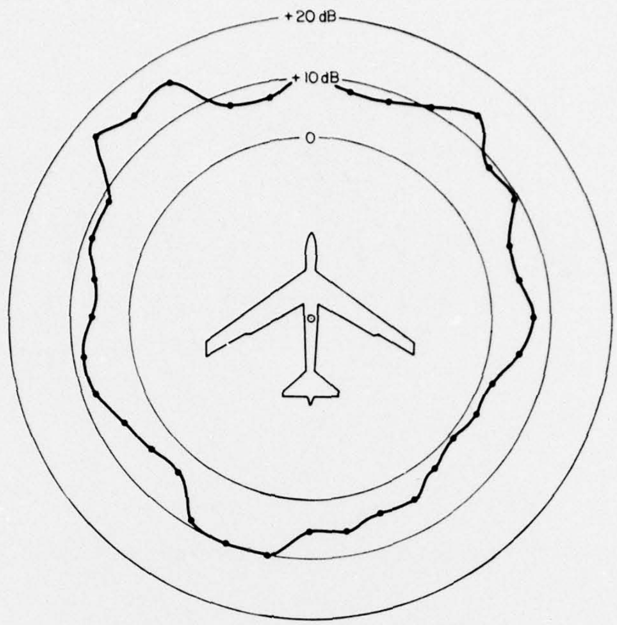

Figure 9. Maximum Variation in Received Signal

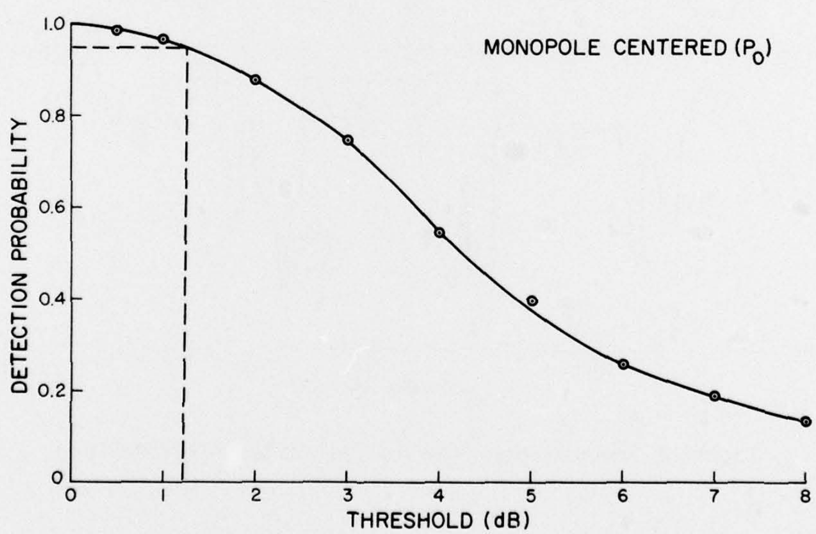

Figure 10. Detection Probability as a Function of Threshold

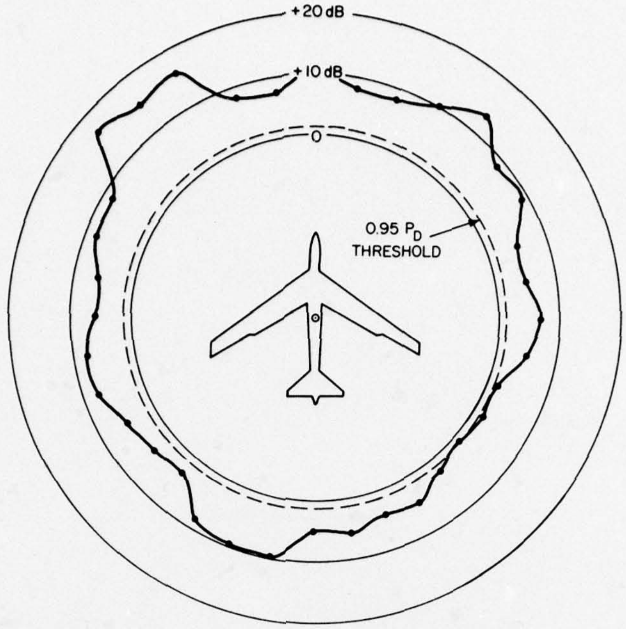

Figure 11. Detection Sensitivity With Monopole Centered

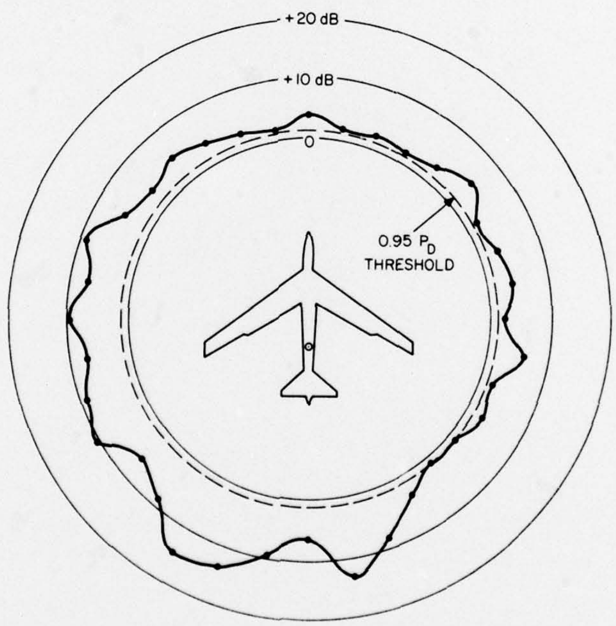

Figure 12. Detection Sensitivity With Monopole 25 Feet Aft

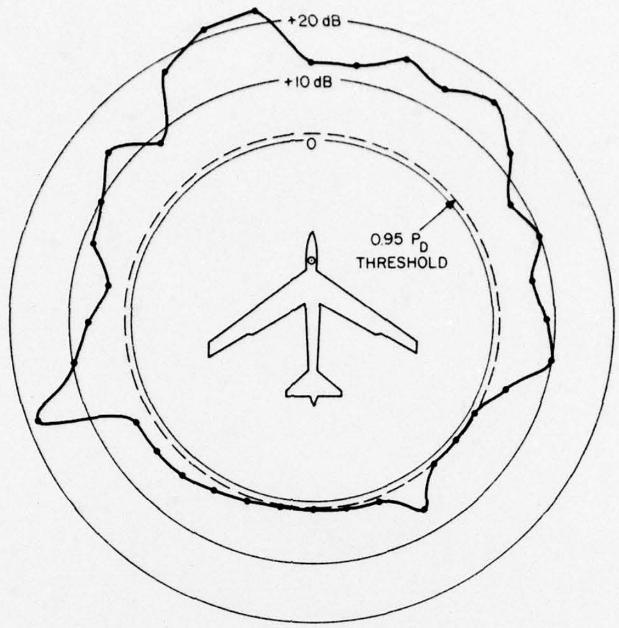

Figure 13. Detection Sensitivity With Monopole 50 Feet Forward

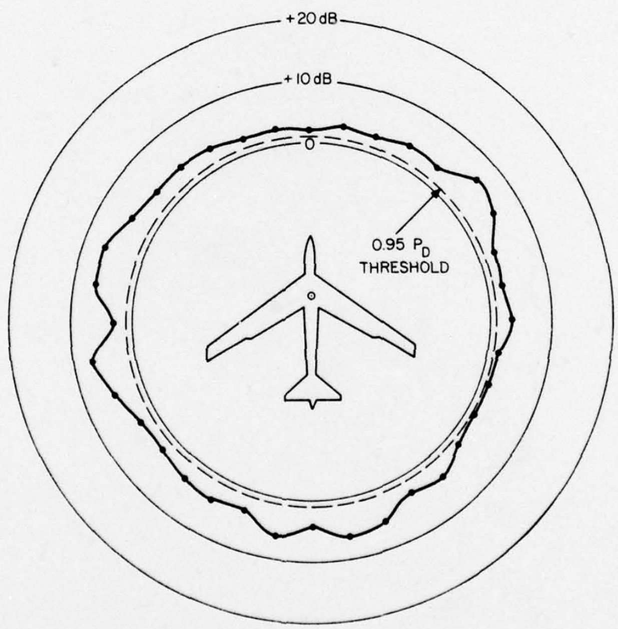

Figure 14. Detection Sensitivity With Monopole 25 Feet Forward

For the aft position P_1, the sensitivity plot, shown in Figure 12, increases toward the tail of the aircraft and decreases to some degree in the front of the aircraft. The results for the most forward location P_3 are the reverse of this. Here Figure 13 shows that the sensitivity is greatly enhanced in front of the aircraft and diminished behind it. For the two inner locations, P_0, and P_2, the sensitivity was found to be more uniform. The response (Figure 14) with the monopole located just behind the front wheels (P_2) was the most uniform, showing a variation of only about 6 dB.

The progressive decrease in sensitivity with azimuth, evident in Figures 11 to 14, is produced by the attenuation of the leaky coaxial cable. As the signal travels from the input toward the load end of the leaky cable, it is continually attenuated, thus reducing the signal available for radiation. No attempt has been made in this system to compensate for this attenuation loss. Several methods exist for eliminating or reducing this effect, including a gradual increase in the coupling coefficient of leaky coaxial cable to compensate for attenuation losses.

3.2.2 EFFECT OF AIRFRAME MOTION

This series of measurements determined the sensitivity of the system to airframe motion. It was anticipated that the variation in signal level would be significantly reduced when the 750 ft cable replaced the smaller one of 500 ft, because the larger perimeter extended beyond the wing tips of the aircraft.

The received signal was again recorded while the wing was manually displaced in synchronism with its natural motion. The amplitude was approximately 1 ft, reckoned at the wing tip. This procedure was repeated for the four monopole positions previously described. In contrast to Figure 6, only discrete values for the maximum variation observed are shown in Figure 15 for each of the monopole locations. The results indicate that the response for the centrally (P_0) located monopole and the most forward (P_3) monopole exceeded the threshold required to declare an intrusion with a P_D of 0.95. Thus, a wind strong enough to deflect the wing tip 1 ft would produce a false alarm when the monopole was placed at either of these locations. However, when the monopole was positioned nearest the tail, the maximum variation was only 0.5 dB, a value insufficient to produce a false alarm. The results showed that for location P_2 just behind the front wheels, the variation in received signal was inconsequential.

Location P_2 was the least sensitive to wing motion and provides the most uniform azimuthal sensitivity. This location yielded the best overall system performance.

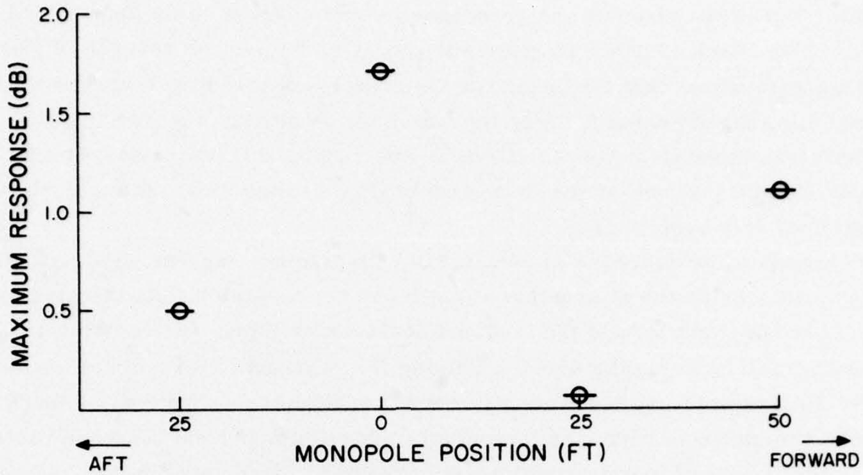

Figure 15. Variation in Received Signal Caused by Wing Motion

3.2.3 CONTAINMENT ZONE

An important requisite of any intrusion-detection system is that its zone of detection or containment be well defined. This is especially important for aircraft protection systems where normal nearby vehicle activity must not be sensed, producing an alarm.

To evaluate this aspect of system performance, an automobile was driven around the aircraft 5 and 10 ft outside the cable's perimeter. The resulting variation in received signal is plotted in Figure 16 as a function of azimuth. The response at the 5-ft distance was sufficient to produce an alarm near 90°. This azimuth corresponds to a peak in the sensitivity curve, as shown in Figure 13. However, variations produced by vehicular motion at the 10-ft distance were insufficient at all azimuths to cause a false alarm.

3.2.4 ADDITIONAL DETECTION SENSITIVITY TESTS

Some additional tests were made to verify the system detection sensitivity. These consisted of radial walks and specialized crossings where the intruder passed over the cable on a supporting framework. Other measurements were made to evaluate system response when the intruder was crawling or creeping. Observations were also made of the effect of an automobile crossing the cable.

The values listed in Table 1 for the signal level changes are averages of several crossings made over a 6-degree region centered at the indicated azimuth. For example, the crossings at 180° produced signal variations ranging from 1.3

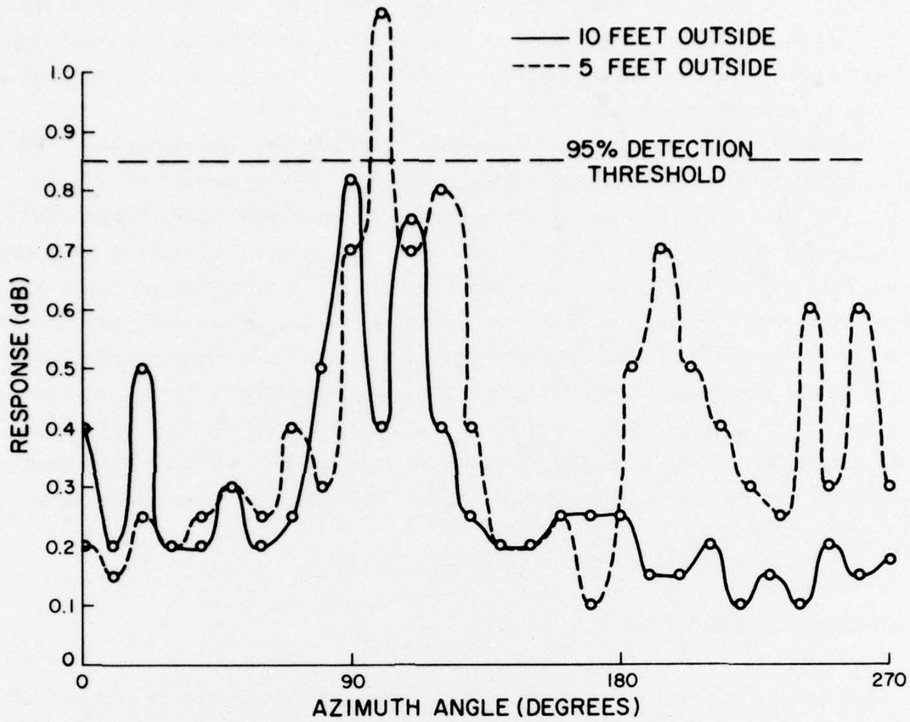

Figure 16. Variation in Received Signal Caused by Nearby Vehicles

Table 1. Tabulation of Response to Various Cable Crossings

Type of Crossing	Azimuth	Average Maximum Signal Change (dB)
Walk	0^{o}	2.8
	180^{o}	1.7
	270^{o}	2.3
Creep	0^{o}	1.5
	270^{o}	1.8
Crawl	270^{o}	1.3
Walk-Elevated 10"	0^{o}	2.2
	270^{o}	1.2
Walk-Elevated 16"	0^{o}	1.5
Car	0^{o}	3.0

to 2.1 dB. The spread in observed values was due to the fine structure of the electromagnetic field around the leaky coaxial cable and to the precise phase of the perturbing signal as the penetrator's path varied during repetitive crossings. This deviation in response was well within the range expected.

Examination of Table 1 shows a number of trends that are important. First, it is evident that a walking intruder produces a strong response at all angles. Second, the signal variation diminishes as the intruder's effective height decreases. Comparison of the signal variation at 270° shows a steady decrease in response as the intruder's position changes from walking upright, to creeping on hands and knees, to crawling. The response was especially reduced, sometimes below the required threshold, when the intruder crawled, his motion along a radial being normal to his longitudinal axis. Third, there is also a steady decrease in system response as the intruder crosses the cable at successively increasing heights above the cable. In addition, the response to an automobile is not dramatically larger than that produced by a human frame. This has also been observed in other leaky coax systems.

4. SUMMARY AND DISCUSSION

The results of the tests outlined in this report demonstrate the viability of the monopole-leaky coaxial cable intruder-detection system. Three favorable characteristics were noted:

a. Absence of shadowing by wheels, wing tanks, doors, or other airframe obstacles;

b. Minimal effect of wind-induced airframe motion on system performance;

c. A well-defined and contained detection zone.

The detection sensitivity of the system was minimally affected by monopole location, so the deployment of the system was noncritical. The principal difference observed during monopole position variation was an increase in the sensitivity of the sector nearest the monopole. This effect is apparent in the sensitivity curves shown in Figures 11 through 14. Also apparent in these curves is a steady decrease in sensitivity as the angle from the input (Figure 3) of the leaky coaxial cable increases. This effect, due to the attenuation of the leaky cable, causes the signal radiated from a given section of the cable to be smaller than that radiated from the preceding section. There is a discontinuity in the level of the radiated field at the end of the cable equal to the cable attenuation. This is about 16 dB for a 750-ft cable.

It is especially significant that there were no sectors where detection sensitivity was unacceptably low. Although line of site from the intruder to the monopole

antenna was blocked by the wheels of the aircraft for intrusions along both the 0° and 180° radial (Figure 17), detection sensitivity for these intrusion paths was more than adequate (see Table 1 and Figures 11 to 14). This was due to the long wavelength (3 to 6 meters) radiation employed.

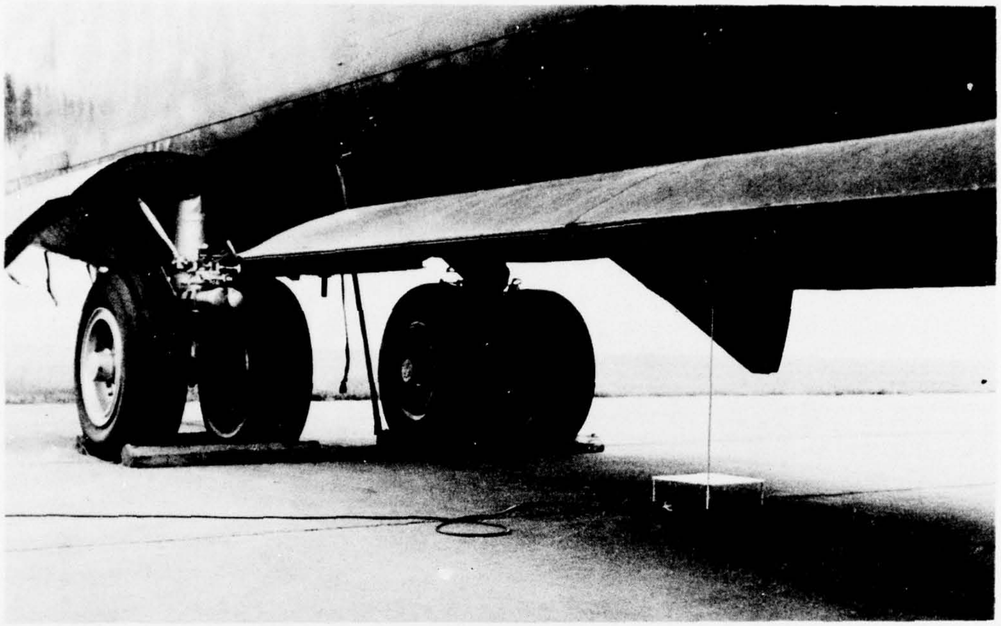

Figure 17. Photograph of Monopole Antenna Showing Proximity to Wheel Assembly

The sensitivity of the system to wing motion was tested and found to be partially dependent upon the location of the monopole. The results indicated that positioning the monopole behind the front wheels made the system relatively insensitive to the motion of the wings. Wind-blown engine-cover lanyards, safety flags, and control surfaces did not appear to influence operation. The numerous safety flags attached to the aircraft were blown about continuously during the tests (Figure 2). The wind, in fact, randomly moved the elevators through their maximum range of displacement with no effect noted on system performance.

It was also noted that the diurnal variation in wing position produced by solar heating did not affect the RF field characteristics. Any influence that this might have would have been eliminated in an operational system by the long-time constant a.g.c. or filtered out by a band pass filter.

Tests done to identify the zone of containment of the detection field showed the system sensitivity to decay rapidly outside the leaky cable. The results in Figure 16 indicate that vehicles moving more than 10 ft outside the cable would not be detected, even in the most sensitive sectors.

Another aspect of the system tests that has not yet been discussed is the role the nature of the ground surface beneath the aircraft plays in affecting system performance. For these tests, the B-52 was parked near the edge of a concrete ramp. Its fuselage, behind the rear wheels, extended over a field of grass adjacent to the ramp. Some sections of the ramp were reinforced while others were not. Nevertheless, no difference in performance was observed when the leaky coax cable was unreeled over these different surfaces. In addition, tests performed on a similar system showed that performance was little affected by snow, ice, and rain.

The deployment configuration of the system would be determined by the particular application required. If permanency were desired, the cable could be embedded into a concrete surface. The RF properties of concrete at VHF would not degrade performance. The monopole could also be mounted in a receptacle embedded in the ramp surface. Alternately, the monopole and system instrumentation could be installed in the aircraft, with only the leaky cable on the ground. For temporary or portable use, the cable might be carried in the aircraft and deployed after the aircraft was parked. The monopole and its associated instrumentation could again be installed in the aircraft, or be portable and placed under the aircraft during deployment. It is estimated that one person could deploy a portable system in 15 min or less. This meets the deployment requirements set forth by the Air Force[3, 4] for mobile (quick reaction) systems.

In conclusion, the tests described in the previous sections established the validity of the VHF techniques applied to the problem of detecting intruders.

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3. System Specification for Base and Installation Security System (BISS) ESD-AFSC. Base & Installation Security System Program Office. Specification Number: BLS-S4S-10000 (Formerly: A63714-64715 BIS). Code Identification: J0464, 1 November 1973.

4. Master Development Plan for the DOD Base & Installation Security System, ESD-AFSC, April 1976.

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